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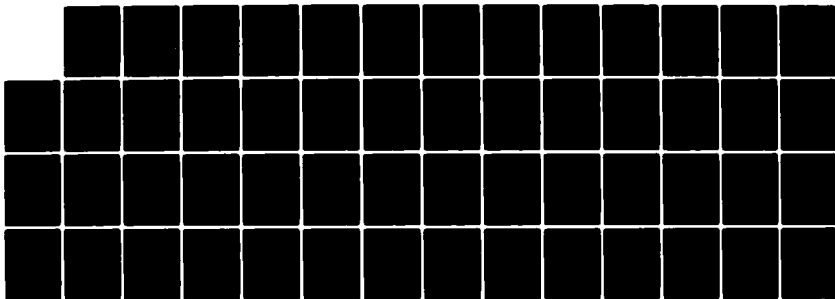
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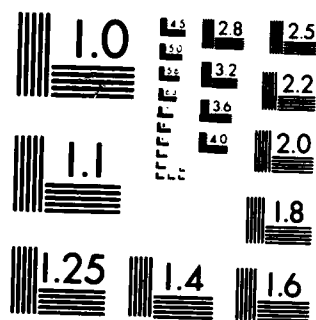
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# ANALYSIS OF RADIATION EXPOSURE, 2ND MARINE CORPS PROVISIONAL ATOMIC EXERCISE BRIGADE, EXERCISE DESERT ROCK V, OPERATION UPSHOT-KNOTHOLE

Science Applications, Inc.  
P.O. Box 1303  
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5 February 1982

Technical Report

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## TABLE OF CONTENTS

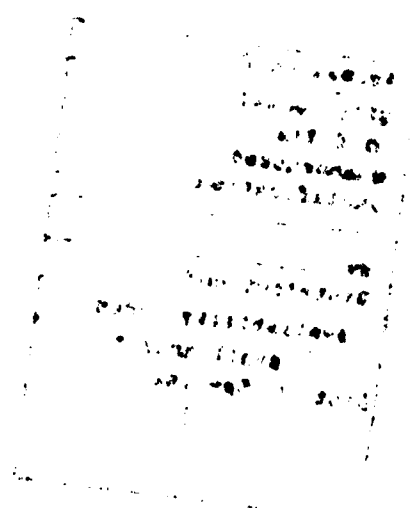
<u>Section</u>	<u>Page</u>
List of Illustrations .....	2
1 INTRODUCTION AND SUMMARY .....	3
2 OPERATIONS .....	6
2.1 Shot Data .....	6
2.2 Participants .....	6
2.3 Concept of Operations .....	7
2.4 Pre-Shot Operations .....	9
2.5 Shot Scenario .....	10
3 INITIAL RADIATION .....	13
3.1 Computational Method .....	13
3.2 Results .....	16
4 RESIDUAL RADIATION .....	18
4.1 Radiological Safety and Radiation Measurements .....	18
4.2 Pre-Shot Radiation Exposure .....	22
4.3 Shot Day Exposure .....	22
4.4 Summary of Residual Radiation .....	30
5 UNCERTAINTY ANALYSIS AND TOTAL DOSE DETERMINATION .....	32
5.1 Uncertainty Analysis .....	32
5.2 Total Dose Summary .....	37
6 DOSIMETRY .....	38
6.1 1st Battalion, 8th Marines .....	38
6.2 2nd Battalion, 3rd Marines .....	40
6.3 Marine Air Group-16 .....	41
6.4 Headquarters .....	41
7 CONCLUSIONS .....	42
References .....	44



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## LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1-1	Selected Shot Locations, Operation Upshot-Knothole .....	4
2-1	Planned Marine Brigade Maneuver, Shot Badger .....	8
2-2	Actual Marine Brigade Maneuver, Shot Badger .....	11
3-1	Shot Badger Initial Gamma Dose .....	17
4-1	Shot Badger Residual Radiation and Troop Movements .....	31



## SECTION 1 INTRODUCTION AND SUMMARY

This report presents an analysis of nuclear radiation exposure for personnel of the 2nd Marine Corps Provisional Atomic Exercise Brigade during their participation in Exercise Desert Rock V (Operation Upshot-Knothole) at Nevada Proving Grounds (now Nevada Test Site) in 1953. These units were part of a brigade maneuver that was controlled by command and staff elements of a Marine division and brigade, the other maneuver units of which were simulated. The exercise took place over a period of a week, during which time the marines trained, rehearsed, observed the nuclear burst designated Badger, conducted their maneuver, and viewed the effects of the nuclear burst on typical military equipment.

The brigade activities are examined for the period of residence at Camp Desert Rock in mid-April 1953. Figure 1-1 shows the features of relevance to brigade activities in Nevada Proving Grounds. Although there was general participation in only one actual burst, the residual radiation from all previous bursts in Operation Upshot-Knothole was examined to determine the dose contribution to the marines during all their activities. Time-dependent position information is determined and presented in order that a complete exposure analysis can be performed. External dose is reconstructed and the uncertainties associated therewith are calculated.

Several documents were available from which to piece together a description of the events and activities in sufficient detail to facilitate meaningful analysis. After-action reports of the Marine Brigade (including comments, recommendations, and endorsements) and Exercise Desert Rock V describe the operations as they occurred, both for the maneuver elements and for other units that related to brigade activities. Planning documents were used to augment activity descriptions and to assist in the interpretation of some unclear passages. The above were supplemented by military judgment for some of the unstated details of troop movements necessary for exposure analysis.



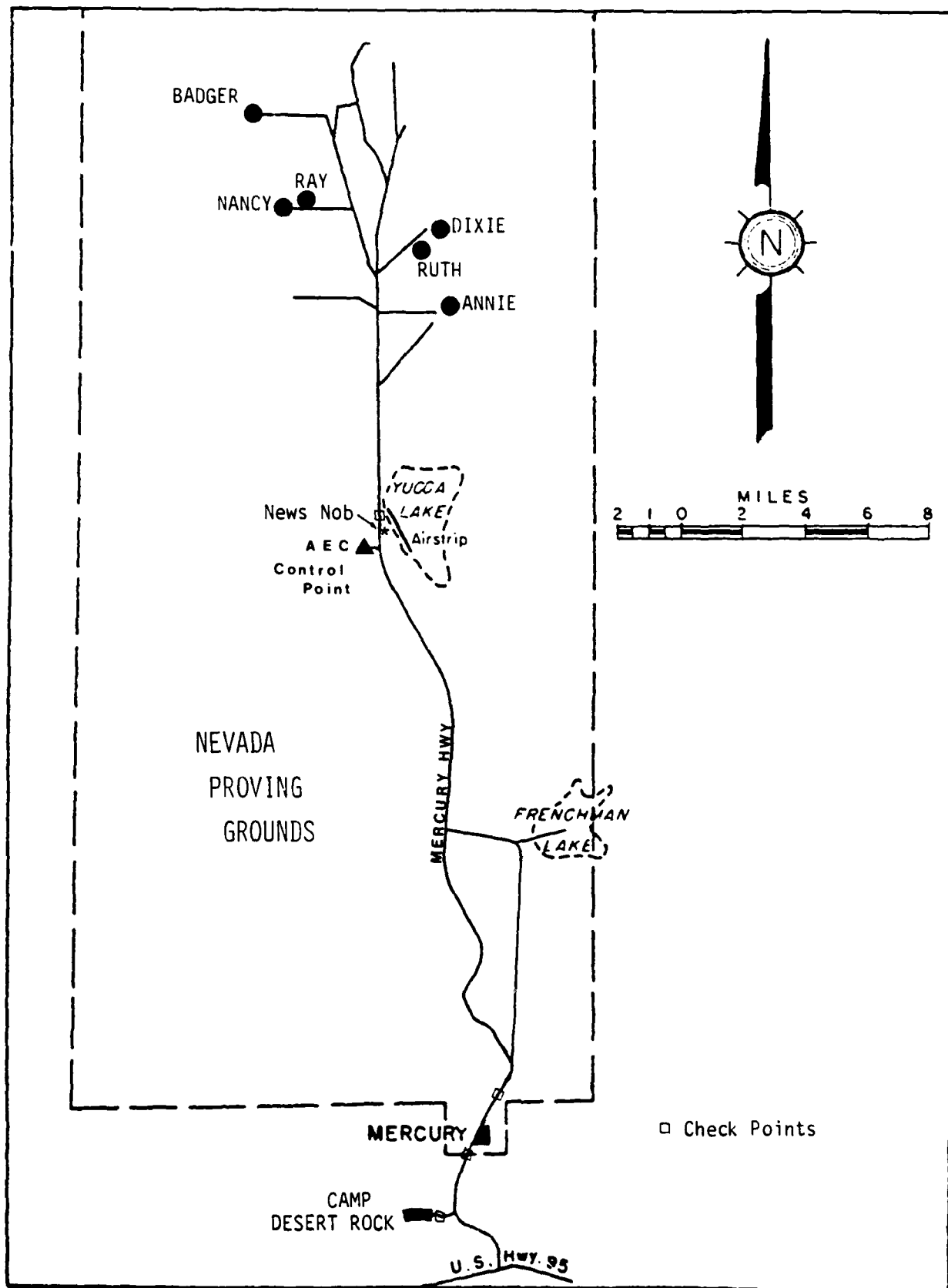


Figure 1-1 Selected Shot Locations, Operation Upshot-Knothole

A major obstacle to the preparation of this report was the lack of systematic radiological survey data for the area of brigade operations. The usual survey data were demonstrably inadequate for resolution of the radiation environment encountered by the marines. However, the limited rad-safe data reported by the marines and by other Desert Rock V participants proved sufficient for a satisfactory reconstruction of the dose to major elements of the Marine Brigade. Either mean or high-sided dose estimates are provided for all major elements. Reasonable constraints on the maneuvers and the radiological environment form the basis for an uncertainty analysis.

Important data for this exercise exist in the form of film badge dosimetry. Although film badges were issued to the marines on a limited basis only, a significant and representative portion of these dose records is available. These data are used to verify the calculations and to identify certain details of brigade activities.

Major findings of this report are:

- o The radiation exposure to troops of the 2nd Marine Corps Provisional Atomic Exercise Brigade was due almost entirely to residual radiation from Shot Badger.
- o Personnel of the 1st Battalion, 8th Marine Regiment, have film badge readings as high as 7.1 rem, which exceeds the Exercise Desert Rock V dose limit of 6 rem. The calculated gamma dose for the most-exposed personnel of the battalion is  $4.7^{+2.1}_{-2.3}$  rem. These doses were accrued during close passage of the nuclear cloud stem and while seeking areas less contaminated by the fallout.
- o Personnel of the 2nd Battalion, 3rd Marine Regiment, have calculated gamma doses of  $3.0^{+1.1}_{-1.2}$  rem, resulting from their tour of the equipment display area. Corresponding badge readings averaged 3.3 rem, and no badges exceeded the 6 rem limit.
- o Brigade Headquarters personnel received doses calculated to be  $3.7^{+0.8}_{-1.2}$  rem. This compares well with the corresponding average of 3.5 rem from limited records.

## SECTION 2

### OPERATIONS

Shot Badger was the sixth in a series of eleven nuclear tests conducted at the Nevada Proving Grounds in 1953. The series of shots is known as Operation Upshot-Knothole. Military exercises conducted in conjunction with this operation were named Exercise Desert Rock V. Battalion-size units conducted post-shot maneuvers in conjunction with several of the shots. Shot Badger was the only shot in which personnel of the 2nd Marine Corps Provisional Atomic Exercise Brigade (MCPAEB) participated in a tactical operation.

#### 2.1 SHOT DATA (References 1, 2)

Date: 18 April 1953, 0435 hours, Pacific Standard Time  
 Location: Area T-2; UTM Coordinates 784104;  
 Yield: 23 KT on a 300' steel tower

#### 2.2 PARTICIPANTS - 2nd Marine Corps Provisional Atomic Exercise Brigade\*

	<u>Approximate Personnel**</u>
Headquarters, 2nd MCPAEB	152
1st Battalion (-) (Reinf), 8th Marine Regiment	862
H&S Company	
Company A	
Company B	
Company C	
2nd Battalion (-) (Reinf), 3rd Marine Regiment	907
H&S Company	
Company D	
Company E	
Company F	
Marine Air Group 16 (Helicopter Transport) (MAG(HR)-16) (-) (Reinf)	220
Marine Helicopter Transport Squadron 162 (-)	
Marine Helicopter Transport Squadron 163 (-)	
Marine Helicopter Transport Squadron 361 (-)	
Marine Helicopter Transport Squadron 362 (-)	
Marine Helicopter Transport Squadron 363 (-)	

TOTAL 2,167 [sic]

\*Activated on 2 March 1953. Subordinate units placed under the brigade's operational control on the following dates: 2nd Bn/3rd Marines, 25 March 1953; 1st Bn/8th Marines, 1 April 1953; MAG(HR)-16, 25 March 1953.

\*\*Reference 5

## 2.3 CONCEPT OF OPERATIONS

The exercise was designed to achieve the following objectives (Reference 5).

- To familiarize personnel with the effects of nuclear weapons.
- To test and further develop tactics and techniques for placing helicopter-borne forces on objectives immediately following a nuclear burst.
- To afford commanders and staffs realistic training in planning and conducting operations that are supported by nuclear weapons.
- To provide realistic training in radiological survey operations.
- To familiarize personnel with the individual and collective means of protection from the effects of nuclear weapons.

Because of the short time interval between the activation of the 2nd MCPAEB (2 March 53) and the originally scheduled date (11 April 1953) for Shot Badger, maneuvers planned for this shot were not very complex. The basic maneuver plan called for all marines (except helicopter crews) to observe the shot from trenches in a simulated beachhead 4000 yards SSW of GZ. Ten minutes after the detonation, the 1st Battalion, 8th Marines (on the right) would begin a ground assault toward an objective area approximately 2000 yards from ground zero (GZ) (see Figure 2-1). Simultaneously, the 2nd Battalion, 3rd Marines (less Company E) would start a ground assault along the left (west) flank toward a second objective area, 2000 yards to their front. The brigade headquarters would follow the advancing battalions, maintaining a position between the two units. When the maneuver ended, the assault troops were to assemble and move administratively on foot through the display area. Equipment was located in groups placed at 500-650, 1000-1090, and 1700-1730 yards from GZ. Uniformed mannequins were located at the latter range and at 2600 yards (Reference 3).

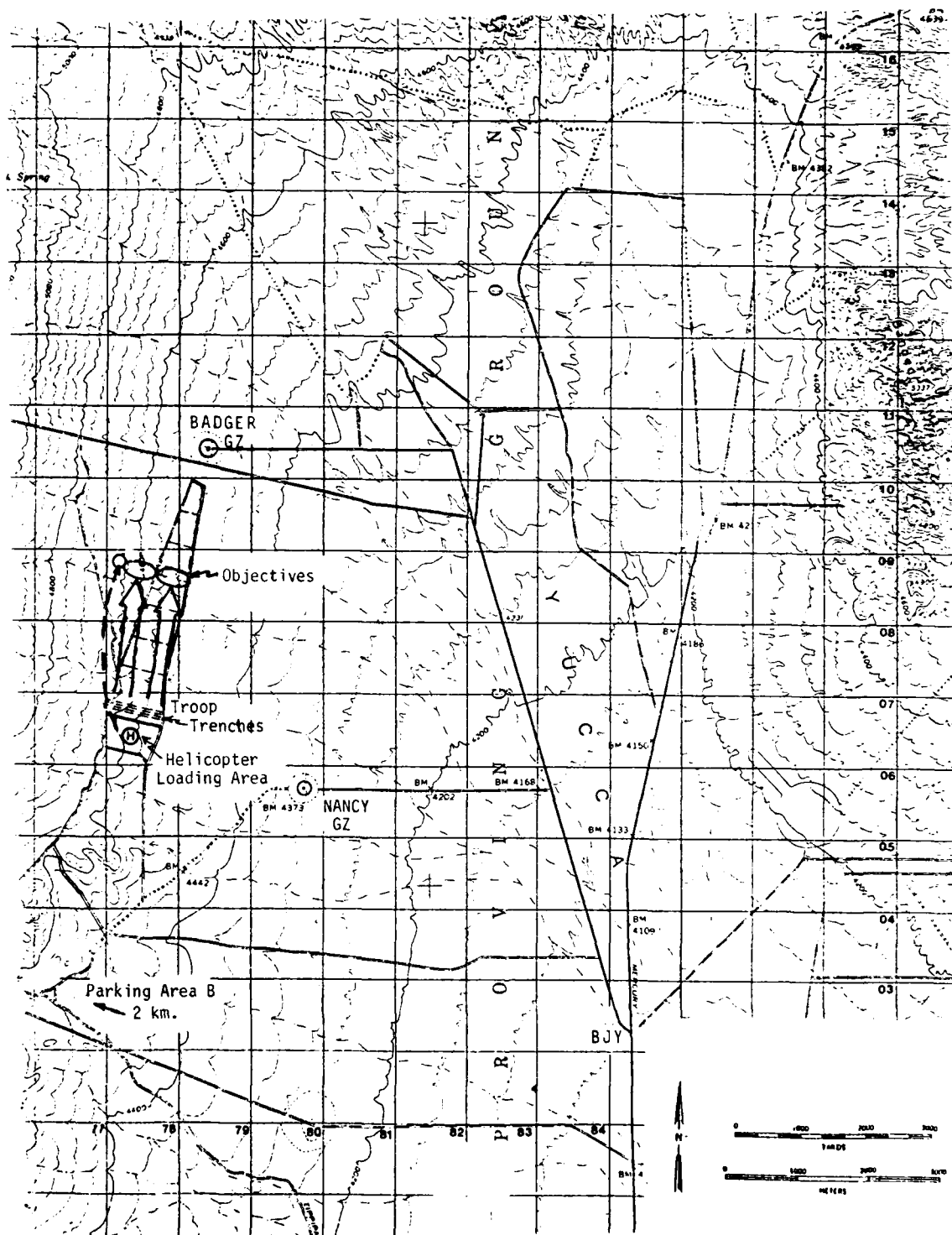


Figure 2-1. Planned Marine Brigade Maneuver, Shot Badger.

Within minutes after the shot, 39 helicopters from MAG-16 would move from the helicopter staging area (at the airstrip on Yucca Lake) to the helicopter loading zone, south of the trench area (see Figures 1-1 and 2-1). Upon landing, two helicopters would embark radiation survey teams and transport them to a third objective area, located to the west of the two battalion objectives. When the area was declared radiologically "safe", all helicopters would embark Company E, 2nd Battalion, 3rd Marines, and transport them to that objective.

Upon completion of the airlift, the helicopters were to return to the vicinity of the trenches. From there the air group personnel would be transported by bus through the equipment display area, where they would view the effect of the detonation on the equipment and materials.

#### 2.4 PRE-SHOT OPERATIONS

On April 6, 1953, 75 Marine Corps personnel, members of the advance party of the 2nd MCPAEB, observed Shot Dixie from News Nob, 10 miles away. This weapon, with a yield of 11 KT, was detonated at a height of 6020 feet over area T-7(3) (coordinates 871045). The men returned to Camp Desert Rock shortly after the detonation.

On April 11, 1953, 25 brigade officers witnessed the detonation of Shot Ray, a 0.2 KT device atop a 100-foot tower in Area 4, coordinates 806060. They saw the shot from News Nob, 11 miles from GZ, and returned to Camp Desert Rock shortly thereafter.

Three days after the arrival at Camp Desert Rock of the main body of the 2nd MCPAEB, a complete rehearsal of the operations for Shot Badger was conducted on 16 April 1953. All brigade personnel arrived in the trench area by 1005 hours in preparation for a simulated detonation at 1051 hours. Immediately after the simulated detonation, the troops attacked north toward their assigned objectives. The Company E airlift to its objective was completed by approximately 1130 hours, and the helicopters returned to Camp Desert Rock at 1220 hours. The ground attacks were halted at a pre-designated location; the

troops then moved through the equipment display area to note its pre-shot condition prior to their departure for Camp Desert Rock at 1345 hours.

At the conclusion of the rehearsal, it was determined that the operation plan was basically sound. The only changes made were in connection with the helicopter lift. These changes involved reducing each helicopter load to three men (plus crew) instead of five because of the density altitude and atmospheric conditions at the maneuver area (Reference 5).

## 2.5 SHOT SCENARIO

Marine troop movement began at 1700 hours on D-1 (17 April) when 39 helicopters flew from Camp Desert Rock to the staging area at Yucca Lake. They remained at this location until after the shot. At 2317 hours on D-1, all maneuver troops and the ground echelon of MAG-16 departed Camp Desert Rock by vehicular convoy up Mercury Highway (see Figure 1-1). They arrived in the trench area at approximately 0255 hours on 18 April. Prior to entering the trenches at 0425 hours, the troops received a final orientation on the effects of nuclear weapons and the safety procedures to be observed (Reference 5).

Shot Badger was detonated on schedule at 0435 hours. After the shock wave passed the trenches, the troops (the 1st and 2nd Battalions) prepared for the attack on their respective objectives (see Figure 2-2). The 1st Battalion, which was attacking on the right flank, turned west after encountering a highly contaminated area within 500 yards of the trenches. Because the cumulative dose received by some personnel during this detour, as noted by pocket dosimeters, exceeded the maneuver guideline, the battalion was ordered to terminate its maneuver. They returned to the trench area, where they remained until the exercise was completed. Meanwhile, the 2nd Battalion (less Company E) advanced in its zone of action (left flank) as planned (Figure 2-2) and reached its objective by 0605 hours (Reference 3).

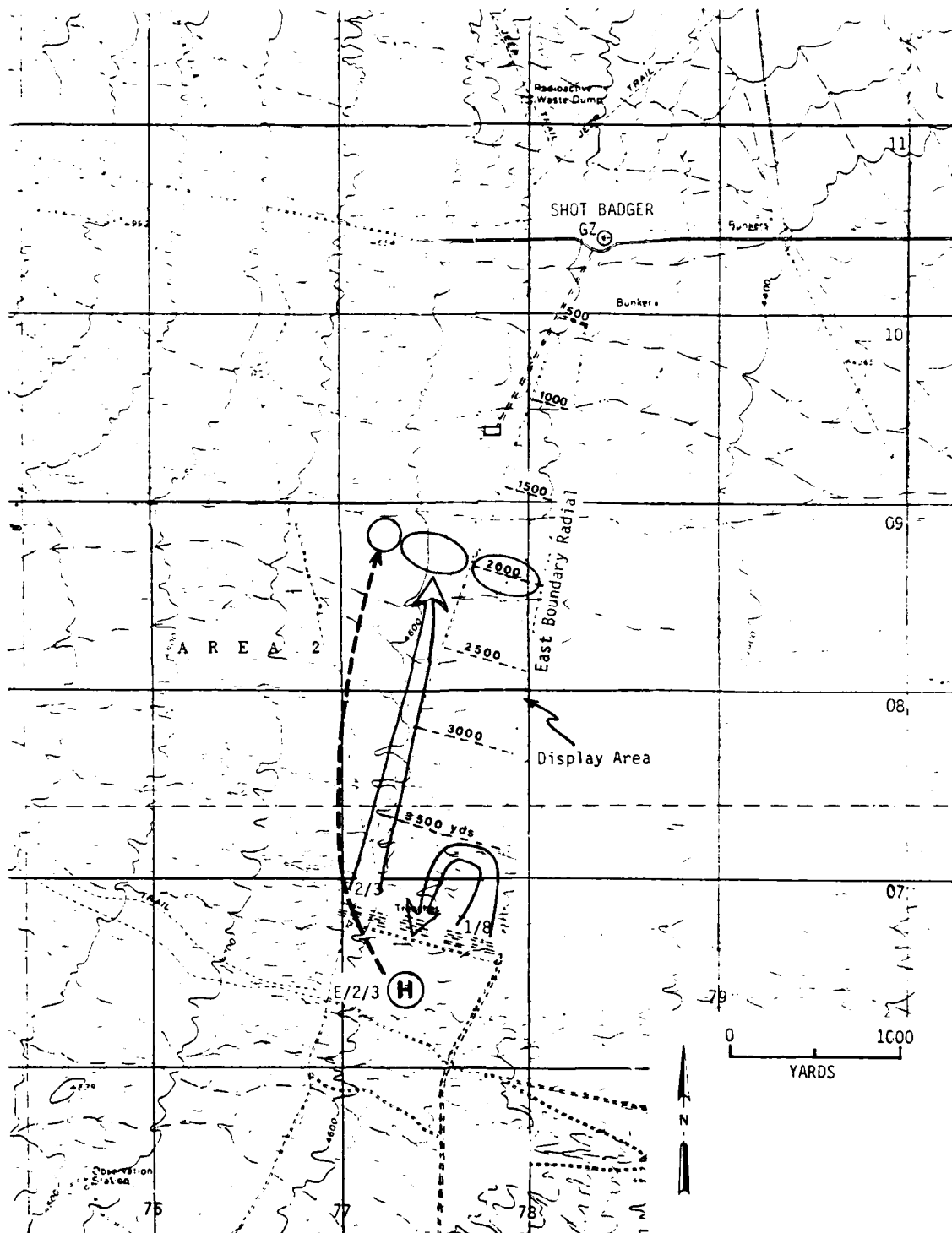


Figure 2-2. Actual Marine Brigade Maneuver, Shot Badger.



At 0446 hours, two pathfinder helicopters arrived at the trenches and embarked the radiation monitor teams that preceeded the Company E airlift to the objective area. The objective was declared radiologically safe at approximately 0455 hours, and the airlift was completed at 0525 hours (Reference 5).

Upon completion of the airlift, the helicopters returned to the embarkation area behind the trenches. From there, the helicopter crews and ground echelon were transported through the display area via bus convoy (Reference 5). It is estimated that the tour of the display area was completed shortly after 0600 hours, at which time the crews returned to Camp Desert Rock via helicopter. The ground echelon probably remained in the vicinity of the trenches with the 1st Battalion.

Brigade Headquarters personnel, who had departed the trenches at 0445 hours, preceeded the 2nd Battalion through the equipment display area along the same route as that designated for the 2nd Battalion. They arrived back at the trench area at approximately 0700 hours, where they joined the 1st Battalion and the ground echelon of MAG-16. Upon securing its objectives, the 2nd Battalion formed for the administrative move through the display area. It is estimated that the tour through the display area was completed by 0800 hours. Entrucking the brigade for the return trip was probably accomplished before 0830 hours, with the last march unit departing the trench area at about 0900. The movement to Camp Desert Rock was completed at 1103 hours (Reference 3), nearly on schedule.

The times estimated above are based on plans (Reference 4) that must have been adhered to (except for the 1st Battalion) because the arrival at Camp Desert Rock was nearly on schedule. The presence of contamination of the planned return route, noted in Reference 5 and discussed in Reference 10, would have only minimally delayed the brigade. After earlier (non-Marine) march units had encountered the contamination, an efficient detour would have been arranged in time for the Marine march units.

### SECTION 3 INITIAL RADIATION

Shot Badger is investigated to determine the possible exposure of Marine participants to initial neutron and gamma radiation. This section discusses the general method used to compute the initial radiation dose to personnel.

#### 3.1 COMPUTATIONAL METHOD

Because the personnel were located in trenches at the time of detonation, the calculation of the radiation doses for Marine participants is accomplished in two steps. First, the free-field radiation environment above the trenches is determined. This environment is then used to calculate the radiation doses to personnel in the trenches. This methodology is similar to that used in References 9 and 10.

In the first step, the neutron and gamma radiation environment is determined with computer codes ATR4 (Reference 12) and ATR4.1 (Reference 13). These codes predict free-field neutron and gamma doses in the vicinity of a nuclear detonation. The first code contains provisions to correct for the presence of Nevada soil at the air-ground interface; the second, although based on a West German soil type, contains improved source-energy-dependent correction factors to account for the air-ground interface. Hence, ATR4 is generally used to calculate neutron and neutron-induced gamma radiation, which are sensitive to the hydrogen (water) content of the soil (Reference 14), while ATR4.1 is used to calculate fission product gamma and prompt gamma (emitted directly from the fission reaction) radiation, neither of which is sensitive to the presence of hydrogen in the soil. Neutron doses are calculated from (Ritts) tissue kerma factors, while the Henderson tissue response function is used to determine gamma doses (Reference 12).

Required input to the computer code (ATR) includes the neutron output spectrum of the device, and geometrical and meteorological data. The neutron

output spectrum for Shot Badger was developed by Los Alamos Scientific Laboratory (Reference 17) for use in these calculations. Meteorological and geometrical (e.g., height of burst, ground zero elevation) data are taken from References 19 and 20. The output of ATR--neutron and gamma doses as a function of range--can be compared with existing dose measurements for each shot to gauge the accuracy of the results. Unfortunately, insufficient neutron activation foil measurements were made during this shot to allow experimental confirmation of calculated neutron doses. Only gold foils (to measure low energy neutrons, 0.3 eV), sulfur foils (to measure fast neutrons, 3 MeV), and various experimental materials (i.e., iodine, indium, and zirconium) were used as neutron detectors (References 21, 22, 23). There is an abundance of free-field gamma dose data available (References 24, 25, 26, 3) however, and these are utilized to verify the ATR results.

The second step of the calculation uses the free-field radiation environment to determine the dose within the trench. It is convenient to define a trench factor as the ratio of dose (neutron or gamma) in the trench to dose (neutron or gamma) above the trench. These factors must be calculated for each of the major components of radiation--neutron, secondary gamma (created by neutron capture or inelastic scattering in the atmosphere and ground), local gamma (created locally by neutron capture in the trench walls), and fission product (debris) gamma. It is found that the trench factors depend also on ground range, height of burst, weapon yield, trench dimensions, and depth in the trench. For Shot Badger, the Marine participants were in trenches approximately two feet wide and a minimum of five feet deep. The in-trench free-field neutron and gamma doses for personnel in a crouched position are calculated at a depth of 2.33 feet below the lip of the trench, which corresponds approximately to the mid-torso depth for personnel in this position. For personnel standing upright in the trench, as probably occurred soon after passage of the shock wave, free-field doses are calculated at a point six inches below the lip at the mid-trench position; this corresponds approximately to the location of a properly-worn film badge for a standing observer. Brief discussions of the derivations of the various trench factors are presented in Appendix I of Reference 10.

The in-trench dose (in rads) is converted to an equivalent tissue dose (in rem) using the quality factors and methods prescribed in Reference 15. The rad-to-rem conversion factor for neutrons, derived from calculations utilizing computer codes DOT (Reference 18) and MORSE (Reference 16), is an almost constant value of 13 for the weapon types and range of interest. The quality factor for gamma radiation is taken to be unity. Finally, representative film badge readings for personnel in the trenches are estimated. The factors that are used to convert the in-trench free-field doses to chest-worn film badge readings were developed from calculations utilizing the adjoint mode of the computer code MORSE. These film badge conversion factors are strongly dependent on the posture and orientation of the personnel in the trench; mean values of these parameters were determined from MORSE calculations involving extreme variations in individual posture and orientation. The "dose equivalent in trench" values reported below are the equivalent tissue dose for neutron radiation and the film badge dose for gamma radiation.

The neutron, secondary gamma, and local gamma doses are accrued rapidly (essentially within the first second) after detonation. Thus, the posture in a trench could not be altered significantly during this exposure. The debris gamma dose, however, is delivered over a period of many seconds. Therefore, the possibility of individual reorientation (e.g., standing up) in the trench must be considered. It is unlikely that a person crouched in the trench at the time of detonation would have attempted any significant movement until after the shock wave had passed and the blast winds had subsided. Therefore it is assumed that, within a few seconds after passage of the shock wave, most of the observers were standing upright in the trench, watching the rising cloud. This reorientation changed both the trench factors and film badge conversion factors for such an individual. The methodology used to determine the debris gamma contribution to personnel film badge doses is described in References 9 and 10. It is assumed in these calculations that the participants stood upright in the trenches at three seconds after the shock wave passed their positions, or 13 seconds after the detonation.

### 3.2 RESULTS

The initial radiation dose to those who observed Shots Dixie and Ray from News Nob, more than 10 miles from the burst, was insignificant. The calculated gamma dose-range curve for Shot Badger is shown in Figure 3-1, along with data from References 24, 25, 26, and 3. It is seen that the calculated dose curve agrees well with the Project 6.8a data beyond 1500 yards, but that the general trend of the data indicates that the calculated curve may underpredict at the range of the troop trenches (4000 yards). Therefore, the gamma dose for the range of these trenches is developed by extrapolating from the Project 10.3 data, thereby insuring a conservative (high-sided) estimate. The total gamma dose thus derived is then proportioned among secondary, debris, and prompt gamma contributors using ratios derived from the ATR4 calculation. Appropriate factors (trench and film badge conversion) are applied to each of these components to calculate the total film badge dose (dose equivalent in trench).

The estimated radiation environment at the troop trenches is presented below:

	<u>Neutron</u>	<u>Gamma</u>
Tissue dose above trench (mrad)	<1	150
Dose equivalent in trench (mrem)	<1	6

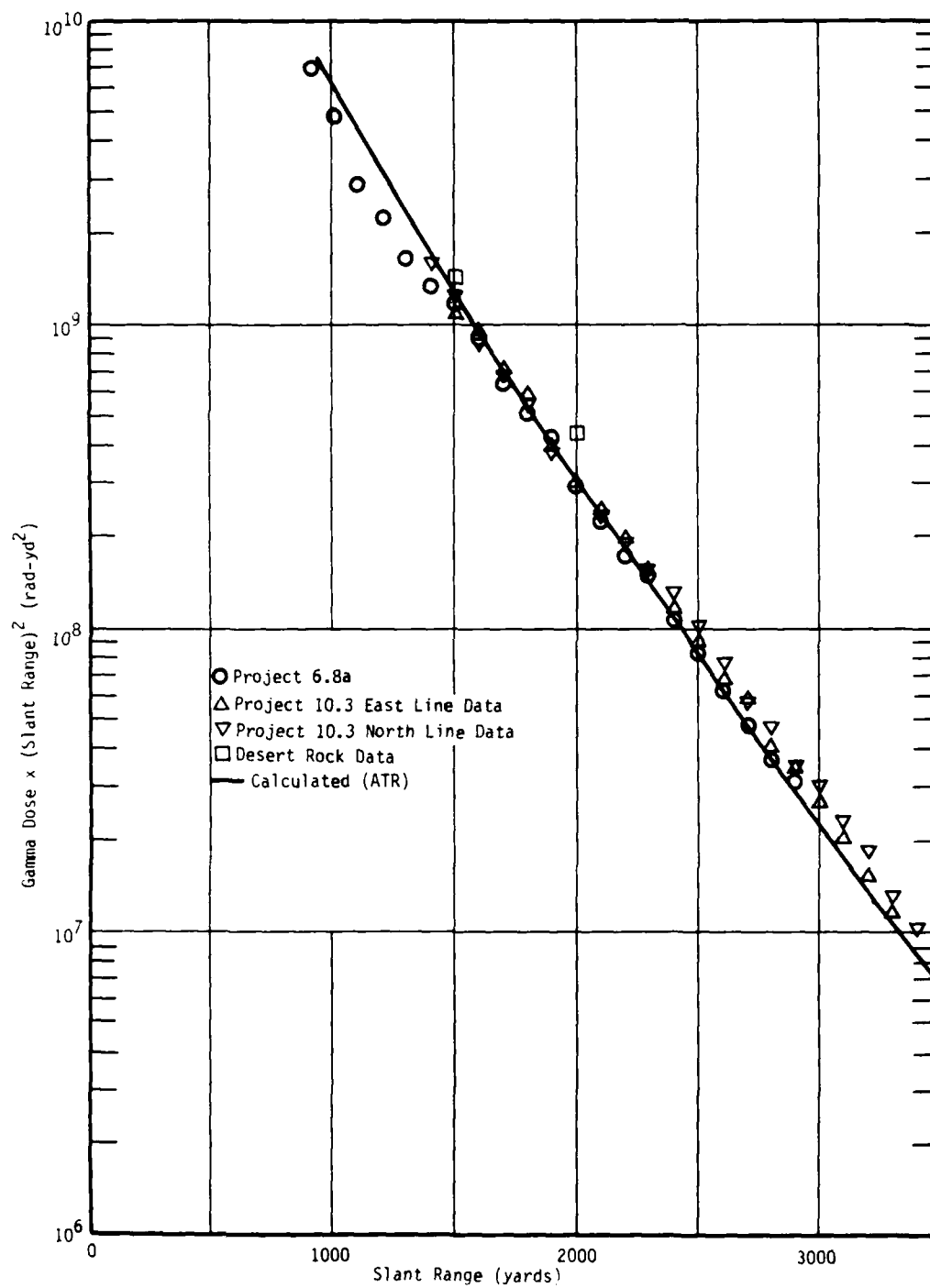


Figure 3-1 Shot Badger Initial Gamma Dose

## SECTION 4

### RESIDUAL RADIATION

Residual gamma doses for brigade elements are reconstructed from the available descriptions of their activities in the post-shot radiation environments. Those environments cannot be determined solely from official radiation surveys because the surveys inadequately characterize the fallout field in the brigade area of operations. Moreover, the surveys did not reflect the intensities encountered by one battalion during passage of the nuclear cloud stem and during fallout deposition. Some other reports of radiation readings are available, fortunately, for estimation of the real-time radiation environments.

Film badge dose estimates must reflect the presence of the human body in the measured radiological environment. Despite the penetrating ability of gamma rays from fission and activation products, the body affords some shielding; hence, the gamma dose to any organ depends on the geometry of the radiation source and the body position. In order to represent reconstructed film badge readings, gamma doses are calculated for the surface of the chest, where a film badge is normally worn. The calculated film badge dose is derived from the integrated free-field gamma intensity through the conversion factor  $1 \text{ r} \rightarrow 0.7 \text{ rem}$  as used in previous reports (e.g., Reference 10).

Because of the limited data concerning the details of troop activities, estimates are required for rates of movement and the stay times at various displays. Rates of movement are generally as described in or inferred from plans, allowing for inertial aspects of large groups as well as terrain and visibility factors. A reasonable and consistent set of parameters is 70 yds/min walking speed and 5 minutes stay time at each Marine equipment display grouping encountered. Additional assumptions are noted as required.

#### 4.1 RADIOLOGICAL SAFETY AND RADIATION MEASUREMENTS

The Marine Brigade participating in Shot Badger operated under a set of radiological procedures somewhat different from those for other Desert Rock V

participants. Although Desert Rock rad-safe personnel provided their usual service of surveying the area of operations, Marine personnel also had a role in rad-safe activities. The Marine Brigade Rad-Safe Section was responsible for decontamination and the issue of film badges (Reference 7). In addition, Marine monitors were to record radiation levels in front of the maneuvering battalions. Although the Exercise Desert Rock rad-safe limit was 2.5 r/hr for pedestrians (Reference 3), the Marine maneuver troops were allowed to traverse areas up to 5 r/hr (Reference 4). No one was to receive more than 6 rem total dose for the exercise. Additional guidance for the Marines was for the battalion commanders to take evasive action if pocket dosimeter readings reached 3 rem.

Control of film badges was a primary function of the Brigade Rad-Safe Section. Operation Plan 1-53 (Reference 7) indicates that film badges were to be issued to all personnel going to the forward area. However, this was superseded by a Camp Desert Rock policy, instituted after Shot Nancy, under which film badges were to be issued to only one person per platoon (Reference 3). Careful records were to be kept from issue on the day before the shot to badge return on shot day. Partial dose records are available; these are discussed in Section 6.

The measurements of three groups are used for gamma dose reconstruction: (1) the Rad-Safe Unit organized under the auspices of the Atomic Energy Commission (AEC) and assigned to Camp Mercury for Operation Upshot-Knothole, (2) the Camp Desert Rock Rad-Safe Section, supported by the 50th Chemical Platoon, which provided radiation safety services to Desert Rock military personnel participating in Operation Upshot-Knothole, and (3) the volunteer observers, who measured gamma intensities along the west boundary of the display area after witnessing the shot from trenches 2000 yards from GZ (Reference 10).

The AEC Rad-Safe Unit was responsible for monitoring the overall radiological conditions, both on- and off-site. Post-shot data from this group included residual radiation intensity mappings of the test site. These are



available for four times within five days after the Badger detonation (Reference 8). Shot Badger iso-intensity contours do not sufficiently resolve the fallout pattern in the maneuver area to allow their use in dose reconstruction (References 3, 5, and 10). Although the contours reflect the high intensity levels that necessitated the 1st Battalion's withdrawal at about 3500 yards from GZ, they greatly overestimate the intensity at 1000 yards from GZ, where the service observers were able to view the displays (References 6 and 10). The contours are of some use, however, in that they provide information regarding the gradient of the intensity along the western boundary of the display area.

Only two statements are available regarding measurements by the Desert Rock Rad-Safe Section. The first team of the 50th Chemical Platoon to survey along the eastern boundary of the display area encountered an intensity of 40 to 50 r/hr shortly after the shot. This unusually high reading, associated with passage of the nuclear cloud stem, quickly fell to 14 r/hr (Reference 3). Not mentioned is the fallout that resulted in the residual reading. The Reference also reports a transient reading of 1 r/hr "at the trench area." This would have been noted in the center of the trench area, between the Marine battalions, where the Desert Rock Control Group was located.

Other Desert Rock rad-safe data consist of dose readings from film badges located at five types of positions at 500-yard intervals from GZ (Reference 3). Although intended to provide a measure of the dose from initial radiation, these badges also recorded a residual radiation dose until such time as they could be recovered. From aerial photographs and Desert Rock V photographs (Reference 3) for several shots, it is noted that the positions ranged from stakes in open terrain at the eastern edge of the display area to bunkers near the midline of the display area.

On the stakes, the badges were fully exposed to the initial radiation. The badge readings at 2000, 2500, 3000, and 3500 yards from GZ were 110, 52, 56, and 8 rem, respectively. Using the range-dose curve in Figure 3-1, the initial radiation contribution is subtracted, leaving residual radiation doses of 35, 39, 53

and 7.5 rem for the four distances, respectively. (At ranges closer to GZ, the initial radiation dose masks any residual dose comparable to these). Fallout gamma intensities can be inferred from these readings if badge recovery times can be determined, if the dose contribution from stem passage can be estimated, and if the time of fallout deposition is identified.

Doses for the other four types of position also demonstrate the influence of residual radiation (ascertained by comparison with doses obtained at other shots). These positions were shallow and deep slit trenches and one- and two-man bunkers. Badges in the bottom of the positions were shielded to varying (but undetermined) degrees from initial radiation, stem-borne activity, and fallout. However, in all four cases, the readings at 3000 yards from GZ were considerably higher than those at 2000, 2500, and 3500 yards. It is possible that intensities at 3000 yards were not much greater, but enough to further delay badge recovery at that distance, resulting in a longer period of dose accrual. The film badge readings do not permit a quantitative assessment of the intensity field. The major conclusion to be drawn from these data is the location and extent of an anomalous region of fallout deposition.

The radiation measurements from the volunteer observers (Reference 6) provide the most dependable information about intensities along the west boundary of the display area. They noted intensities as high as 50 r/hr as the nuclear cloud passed over their trench, 2000 yards from GZ, at about H+7 minutes, but no longer noted these high intensities after they had walked to the west boundary. There, still at 2000 yards, the observers reported readings of about 1 r/hr at nine to eleven minutes after the shot. While walking back toward the main trench area, they reported intensities of 0.5 r/hr at 2100 yards, 0.32 r/hr at 2500 yards, and 0.12 r/hr at 3000 yards from GZ. Corresponding times were 14, 19, and 25 minutes after the shot. The reading at 25 minutes most likely represents the level of activity remaining after the cessation of fallout. It therefore is the most useful measurement for use in dose reconstruction along the west boundary radial.

#### 4.2 PRE-SHOT RADIATION EXPOSURE

Participants in the Marine Brigade Exercise were exposed to residual radiation from Shot Nancy on two occasions. The first was during the rehearsal conducted on 16 April, two days before Shot Badger. The second occurred on shot day when the exercise was conducted in the 25-day-old Nancy field. In both cases, the dose received was small compared to that from Shot Badger.

During the rehearsal, Marine radiation monitors reported residual intensities of 10 to 90 mr/hr (Reference 5). An examination of post-shot surveys of the Nancy fallout field indicates that the residual intensity in the vicinity of the Badger trenches was about 10 mr/hr. Intensities within the exercise area are not resolved by data from the Rad-Safe Unit; however, it should be noted that 100 mr/hr readings had not been reported in the vicinity for more than a week (Reference 8), and thus peak readings rather less than the marines' are implied. In either case, most of the 3½-hour rehearsal was at or near the trenches, so that the total film badge dose was likely about 50 mrem (25 mrem at a minimum).

In the 2- to 3-hour wait at the trench area for the Badger detonation, the troops would have accrued up to an additional 20 mrem from the Nancy fallout. Thereafter, the residual radiation from Nancy was masked by that from Badger and is not calculated separately.

#### 4.3 SHOT DAY EXPOSURE

The residual radiation exposure of the Marine Brigade is calculated for each of the major brigade elements that engaged in distinct activities and for which sufficient information concerning the radiation environment is available. The spacing of the brigade elements within the maneuver area warrants individual dose reconstructions for the four major participating groups: the 1st Battalion, 8th Marines; 2nd Battalion, 3rd Marines; Marine Air Group-16; and 2nd MCPAEB Headquarters.

#### 4.3.1 1st Battalion, 8th Marines

The 1st Battalion, 8th Marines, operated in the eastern portion of the display area, where it experienced high gamma intensities associated with the passage of the nuclear cloud stem and subsequent fallout deposition. Doses accumulated early in its advance exceeded the 3 rem level above which the battalion was required to move out of a contaminated area (Reference 7). Unable to proceed more than 500 yards toward the assigned objective, it nevertheless accrued significant additional dose in evading the area of greatest perceived contamination. As some elements of the battalion exceeded the allowable dose limit of 6 rem during this evasion, the battalion withdrew to the trench area and was not permitted to continue the maneuver or to tour the display area.

Reconstruction of film badge doses for the 1st Battalion is possible only for those elements whose movements can be related to the limited rad-safe data introduced previously. Only the troops on the right flank of the battalion would have both walked near the road (east radial) used by the 50th Chemical Platoon survey team and advanced as far as 500 yards (to near the film badge on the stake). A dose reconstruction for the right flank personnel provides a high-sided dose estimate for the 1st Battalion, as gamma intensities were increasing with distance to the north and east. That the right flank personnel accrued the greatest dose is confirmed by Marine dosimeter readings (Reference 5).

As the limited rad-safe data do not explicitly relate a gamma intensity to a position and time, auxiliary data are used to develop this relationship. The 50th Chemical Platoon survey data require augmentation with respect to position and duration of the intensities cited. For the film badges at positions, the time dependence of intensity must be unraveled from the total badge reading, which represents the time-integrated intensity.

Peak intensities and their duration are related to the movement and dimensions of the nuclear cloud stem. The relevant portion of the stem drifted with the near-surface winds, which were 9 knots at the time of burst (Refer-

ence 3). After a slight shift in wind direction, the MCPAEB estimated a speed of 10 to 15 knots. The low figure, used as being more consistent with the scenario of brigade events, corresponds to movement of about 300 yd/min. At higher speeds, the 1st Battalion's attack, scheduled for 10 minutes after burst, would not have gotten underway before the stem reached its position 4000 yards from GZ. By such time, the stem diameter was roughly 1 mile. Because the stem passed over only part of the display area, the 1st Battalion would not have experienced radiation from the full diameter. Perhaps 1/2 mile, or about 3 minutes worth, of stem passed over them. It is assumed that the radiation dose from the stem is reasonably obtained by associating that duration with the peak intensity (edge effects neglected).

In order to utilize the intensities reported by the 50th Chemical Platoon survey team, it is necessary to demonstrate that these readings were obtained close to the maneuvering 1st Battalion. The survey teams witnessed the detonation from Parking Area B, about 3 miles behind the trenches. At H+5 minutes, or on order of the Exercise Director (Reference 4), they were to move by jeep to locations on either side of the display area at 3500 yards from GZ, where they were to begin surveying toward GZ. Their speed in approaching the display area is not known, but is unlikely to have been as great as 30 mph on the unsurfaced roads. Even at that speed, the team on the east would have taken 8 minutes to travel the approximately 4 road miles to its initial surveying point. If the team departed on schedule, it would have encountered the stem radiation in the 13th minute after burst, between 3500 and 4000 yards from GZ, at which range the 1st Battalion was already maneuvering. Thus, the peak intensity of 50 r/hr encountered by the survey team must have been about the same as encountered by the right flank of the battalion.

Once the survey team encountered radiation, its advance would have been much more circumspect. Taken unawares by intensities ten times their permitted maximum of 5 r/hr, the rad-safe teams may have been uncertain how to proceed. They probably did not progress far in any direction while the stem passed over them. When the intensity subsided only to 14 r/hr, with no

immediate prospects for its dropping to 5 r/hr, they would have withdrawn from the display area. The survey team could not have continued toward GZ without encountering still higher intensities (as can be demonstrated from the high film badge readings on closer-in stakes, regardless of the time of badge recovery). Consequently, both the 50 r/hr and 14 r/hr readings appear to have been relevant to the 1st Battalion's (right flank) exposure.

The statement in Reference 3 regarding the 14 r/hr reading does not clarify whether fallout was essentially complete by the time the stem had passed, in which case  $t^{-1.2}$  decay could be applied to the intensity at subsequent times, or whether fallout deposition persisted, keeping the intensity near 14 r/hr for an extended interval. That fallout deposition continued for a brief interval is deduced from the residual radiation contribution (7.5 rem) to the stake reading at 3500 yards. The aforementioned intensities should roughly apply to this position. Camp Desert Rock evaluators, seeking to recover film badges from the positions, would have arrived when intensities had diminished to 5 r/hr. If 14 r/hr applied at about H+15 minutes, then recovery could have been as soon as H+35 minutes, if  $t^{-1.2}$  decay were immediately applicable. The dose from this exposure in addition to the 50 r/hr for 3 minutes from stem passage is only 5.2 rem. The 7.5 rem is obtained if 14 r/hr persisted until H+20 minutes (from continued fallout), and  $t^{-1.2}$  decay applied thereafter (recovery at 5 r/hr at H+46 minutes)\*.

These results are applied to scenario of 1st Battalion activities to determine the dose to the right flank. Although the stem was observed heading toward the trench area by H+5 minutes (Reference 5), the import of this phenomenon was evidently unrealized; no command decisions are documented therefrom. As initial radiological reconnaissance in front of the battalion would have detected no contamination, the maneuver would have begun as scheduled at H+10 minutes. From about H+12 to H+15 minutes, the battalion would have been exposed to the passing stem. At about H+17 minutes, the battalion had advanced about 500 yards to the 3500-yard line, where it halted, evidently because of a 3.5 rem pocket dosimeter reading (Reference 5). The calculated film badge dose

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\*1r → 1 rem for the unshielded film badge on the stake.

to this point is 2.1 rem. After a wait of about 5 minutes to effect a change of direction, the battalion proceeded westward, likely at a slower pace in order to keep better apprised of the radiological situation. It had time to progress to the midline of the display area and halt when doses in excess of the 6 rem limit were reported, before beginning to withdraw to the trench area at the H+36 minutes cited in Reference 5. Even at the midline of the display area, 3500 yards from GZ, intensities remained high, as evidenced by the film badge reading from the bunker there. The intensity encountered by the 1st Battalion is assumed to have remained constant, except for  $t^{-1.2}$  decay, throughout its westward march. The applicability of this assumption, in light of the readings at the various positions, is examined in Section 5. By the time that withdrawal began, dosimeters read as high as 7.5 rem; the calculated film badge dose to that point is 4.4 rem. In the 500 yards back to the trenches, the intensity dropped dramatically to the insignificant levels encountered by the rest of the MCPAEB. The dosimeters indicated no further dose accrual; the maximum reading back at Camp Desert Rock was still 7.5 rem (Reference 5). A reasonable dropoff in intensity gives an additional calculated film badge dose of 0.2 rem, for an exercise total of 4.6 rem.

With regard to the remainder of the 1st Battalion, it is evident that the left flank and rear elements would have accrued far lesser doses. When the stem passed, some elements would have been no closer to the right flank, at 50 r/hr, than to the Desert Rock Control Group, at 1 r/hr in the center of the trench area. With some type of logarithmic interpolation likely applicable, these troops would have been exposed to less than 10 r/hr. Moreover, those elements that did not advance the full 500 yards before turning would have had less exposure to fallout than the forward companies.

Available documents do not indicate the relative positioning of the companies for the battalion maneuver; this is determined empirically from the dosimetry data and is discussed in Section 6.

#### 4.3.2 2nd Battalion, 3rd Marines

This battalion completed the entire exercise as planned. The first phase, to secure an objective 2000 yards north of the trenches and just west of the display area, was accomplished within 90 minutes of the detonation (Reference 5). Radiation levels along the west boundary of the display area (west radial) are estimated from the volunteer observer measurement of 0.12 r/hr at 3000 yards from GZ, 25 minutes after the shot; the shot-day iso-intensity contours plotted by the Rad-Safe Unit, which imply a factor-of-ten variation in intensity for each 1200 yards; and  $t^{-1.2}$  decay.

After securing the objective, the battalion proceeded through the display area, stopping at the Marine display groupings. Starting at 2000 yards from GZ, the battalion moved northward along the west radial until it reached the displays between 500 and 650 yards from GZ. Unlike the service observers, whose earlier (H+90 minute) movements were limited to the 1000-yard displays (Reference 10), the 2nd Battalion was probably able to view the closest displays without exceeding its 5 r/hr rad-safe limit at their approximate arrival time of H+135 minutes.

The battalion then proceeded to the east radial and turned south toward the trench area, stopping again at each major display grouping. Radiation levels along the east radial are estimated from four sources -- the known observation of the displays at 1000 and 1700 yards by the service observers (within their 2.5 r/hr rad-safe limit), the assumption of similar intensities along the radials at corresponding close-in distances, exponential intensity gradient along the east radial, and  $t^{-1.2}$  decay. At roughly 2800 yards, the battalion had to detour to the west to avoid the heaviest fallout region. Its course likely followed the 5 r/hr limit until intensities decreased near the trenches. The exposure to 5 r/hr is assumed to have persisted to near the trenches.

That intensities would have reached 5 r/hr, as calculated, during the return along the east radial is confirmed by analysis of the film badge reading from the stake at 3000 yards. By the method described previously, the portion of



the dose due to residual radiation, 53 rem, is consistent with recovery (at 5 r/hr) at about H+3 hours, roughly the time at which the 2nd Battalion passed nearby. Readings from other positions at that distance appear to indicate (with badge shielding taken into account) that still higher intensities were present in the vicinity.

The 2nd Battalion is estimated to have received a film badge dose of 2.9 rem during its maneuvers. Almost all of this dose was accrued during the tour of the display area. The largest portion was received while returning to the trenches along the 5 r/hr line. Company E, although airlifted from the trenches to its objective, is calculated to have received a dose of 2.8 rem, similar because it moved through the displays with the remainder of the battalion.

#### 4.3.3 Marine Air Group-16

The dose received by MAG-16 personnel can be estimated from their movements, except regarding the route used by the helicopters in moving from their staging area at Yucca Lake to the Company E loading area to the south of the trenches. Reference 5 states that the helicopters had to "select alternate routes around the atomic cloud and dust area." The reference further states that two pathfinder helicopters arrived at the loading area eleven minutes after the shot to airlift the rad-safe teams to the vicinity of the objective. This time is too early for these helicopters to have encountered the radioactive stem, which was nearer the 3500-yard line at that time. Any route adjustments required of the main body of MAG-16 helicopters would have been to the southeast of the trench area, involving only the helicopter crews enroute to the trench area. The stem was easily visible; thus few, if any, crews would have flown sufficiently close to it to receive more than a transient exposure.

In transporting Company E to the objective (see Figure 2-2), the helicopter unit would have transported the troops in two lifts. Ground intensities along the flight path ranged from a few mr/hr to 0.5 r/hr, as suggested by the volunteer observers' measurements (assumed applicable, as far west as the objective area, at corresponding ranges). At the maximum permitted

height for helicopter flight, 400 feet (Reference 7), the intensity would have been one-fifth as great (Reference 27). For the actual flights, most of the dose was accrued while the helicopters were landed at the objective area. With about 10 minutes total ground time there, it is estimated that the film badge dose during the airborne phase of the operation totaled 50 mrem.

Upon completion of the airlift and return of the helicopters to the trench area, MAG-16 personnel were bused through the display area. For an assumed convoy speed of 15 miles per hour, except 5 mph along displays, the dose received during the time in the buses is estimated at 360 mrem. It is calculated (in the manner described for the 2nd Battalion) that during the return along the east radial, the convoy encountered intensities of 5 r/hr, the rad-safe limit for vehicular traffic, near 2000 yards from GZ. The crossroad at that distance would have provided a return route to the west radial, and thus to the trenches, at lower intensities. The total estimated film badge dose for MAG-16 is about 400 mrem.

#### 4.3.4 Headquarters

Information on the movements of 2nd MCPAEB Headquarters is limited to the pre-exercise schedule of events (Reference 4). Dose reconstruction is based on the assumption that their movement proceeded as planned. Headquarters personnel were to leave the trenches 10 minutes after the shot and return by 145 minutes after the shot. They were to precede the troops through the display area, moving toward GZ on the west radial and returning along the east. It is assumed that they viewed the displays at 500 yards (rad-safe conditions are calculated to have permitted this), although a survey updating the rad-safe limit line may not have been completed by the time of their passage. The return to the trenches most likely required a detour, as described for the 2nd Battalion, beginning around 2500 yards from GZ. The film badge dose received by Headquarters is estimated to be 3.6 rem, the majority of which was received during the return to the trenches.

#### 4.4 SUMMARY OF RESIDUAL RADIATION

Figure 4-1 depicts the radiological situation in the equipment display area at one hour after Shot Badger, based on the foregoing analysis. It should be noted that pertinent activities of the 1st Battalion were prior to one hour after burst, while those of the 2nd Battalion were somewhat thereafter.

The total calculated film badge doses from residual radiation during the rehearsal and on shot-day are summarized for the various elements of the 2nd MCPAEB as follows:

<u>Group</u>	<u>Film Badge Dose (rem)</u>
1st Battalion, 8th Marines	4.7*
2nd Battalion, 3rd Marines	3.0
Marine Air Group-16	0.5
Headquarters	3.7

\*Right flank company only; less for other elements.

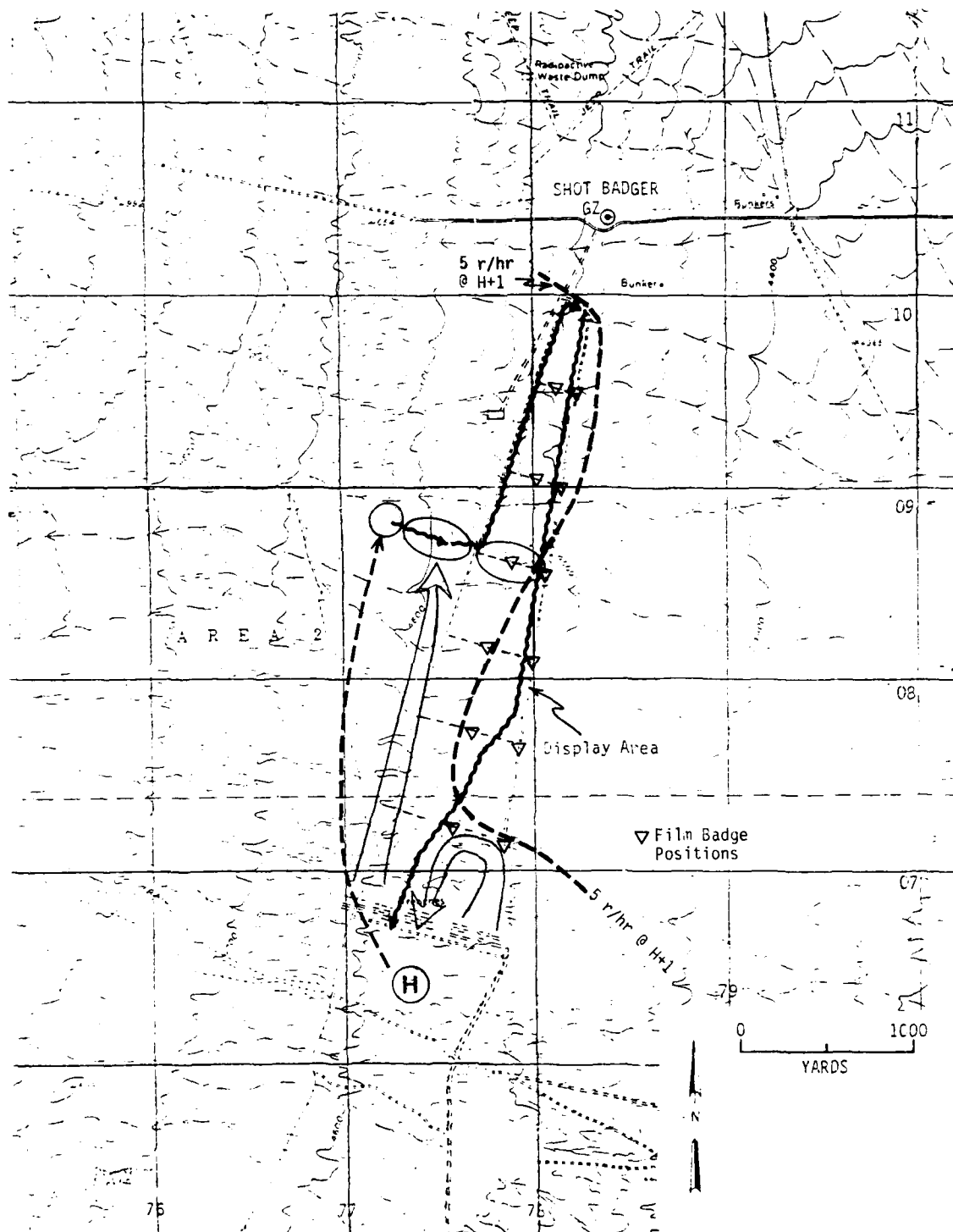


Figure 4-1. Shot Badger, Residual Radiation and Troop Movements

## SECTION 5

### UNCERTAINTY ANALYSIS AND TOTAL DOSE DETERMINATION

The sources of error in the calculation of the more significant doses are examined in order to estimate the uncertainty in personnel dose resulting from 2nd MCPAEB activities. Doses from all activities are summed as applicable to determine the mean total dose to the various units within the brigade.

#### 5.1 UNCERTAINTY ANALYSIS

The group activities resulting in the most significant doses were the aborted maneuver for the 1st Battalion and the equipment display tours for the 2nd Battalion, Brigade Headquarters, and MAG-16. In addition, a significant dose could have been received by MAG-16 helicopter crews if they had flown close to the nuclear cloud stem. The uncertainty in dose accrued from these activities arises from the uncertainties in the gamma radiation environment and in the space-time scenarios of troop movements. Errors in position, time, and gamma intensity are not necessarily independent; where the rad-safe limit line had been established, troops were constrained to intensities of less than 5 r/hr.

The various sources of error are assessed to determine reasonable upper and lower limits of dose. These limits are taken to represent uniform, high levels of confidence in the dose calculations. Accordingly, uncertainties from multiple sources are combined as for continuous (e.g., normal) error distributions. Because the dose limits determined in this section are nearly arithmetically symmetric around the best-estimate doses from Section 4, the error distributions are assumed to be symmetric. Best-estimate doses are then equivalent to mean doses, which may be legitimately added for multiple exposures to find the mean total dose; this may be compared to film badge data or assigned as a personnel gamma dose.

##### 5.1.1 1st Battalion, 8th Marines

Despite the many assumptions and uncertain parameters used in arriving at a dose estimate for the right flank of the 1st Battalion, the range of possible doses depends on only a few. In determining that range, the measurements by the 50th

Chemical Platoon, with all their attendant uncertainties, are not required. Other than the timing of stem passage (with brief duration), which is well established, information regarding the stem and associated gamma intensities is not required. Film badge data from positions in the equipment display area are instead utilized to arrive at a dose range. The reading from the stake at 3500 yards implies a relationship at that position between the dose resulting from stem passage and that from the fallout field. Data from other positions provide an indication of how the intensity may have varied to the west of the 3500-yard stake.

The stake reading assumes a central importance in the determination of the possible dose range because it is quantifiably relatable to the radiation environment and because the right flank reached and halted at its location. Moreover, the (unshielded) badge on the stake lacks the uncertain shielding factor of the other types of position. The implied radiation environment is dependent on the time of badge recovery. The assumption of recovery as soon as the local intensity had decayed to 5 r/hr is supported by the motivation for early recovery -- to minimize the influence of residual radiation on the badge readings, which were intended to be measures of the initial radiation dose. Any later recovery implies lower calculated doses.

To assess the dose from the remainder of the maneuver, intensities at other positions are related to that at the stake. Although the battalion was still approaching it while the stem passed, the residual radiation field, as known, strongly suggests that the marines were less, if not nearly equally, exposed to the stem. While proceeding westward, the battalion was exposed to radiation levels that cannot be assessed directly from the readings at other positions, for which the shielding factors are unknown. Comparison with readings at closer-in positions where initial radiation dominated is not fruitful because of the different shielding of initial and residual radiation. Limited data from Shot Simon in which residual radiation dominated (Reference 3), with a weak azimuthal dependence of intensity, suggest that intensities at the other positions 3500 yards from the Badger GZ were likely within a factor of two of the intensity at the 3500-yard stake. Because the locations of the intermediate positions are not known, nothing more restrictive than the following can be stated: the average intensity along the westward portion of right flank's track was within a factor of two of that (normalized in time) at the stake.

The range of possible doses to the right flank of the 1st Battalion is thus obtained from consideration of all possible partitions of dose at the stake between stem and fallout, and from the range of intensity applicable elsewhere relative to that at the stake, as indicated above. The mathematical combination of these relationships results in a single polynomial expression for dose in terms of a normalized intensity; the expression is maximized using the high side ( $\times 2$ ) of intensities west of the stake and minimized using the low side ( $\times \frac{1}{2}$ ). A maximum film badge dose 2.1 rem in excess of that calculated in Section 4 results from a mixed exposure to stem and fallout radiation; a minimum dose 2.3 rem less than that in Section 4 results from exposure to fallout only. This latter condition is unrealistic in that the marines surely accrued some dose as the stem passed by, but tends to cover the possibility that they were less exposed to the stem than was the stake. The intensities encountered during the battalion's withdrawal would have been similar for the maximum and minimum dose conditions. Consequently, the last increment to dose, during the return to the trenches, would have been similar in either case. Its intrinsic uncertainty is negligible compared to the magnitude of those discussed. The total film badge dose to the right flank of the 1st Battalion is thus calculated to have been  $4.7^{+2.1}_{-2.3}$  rem.

#### 5.1.2 2nd Battalion, 3rd Marines

The three main types of uncertainty in doses calculated for tours of the equipment display area are with regard to the gamma intensity field, the route taken, and the timing of the tour. For groups touring the Badger display area, the upper limit in dose is obtained from consideration of the uncertainty in the gamma field, and the lower limit is from consideration of alternate routes. For the 2nd Battalion, the planned and reported timing of movements considerably constrains estimates of timing of its tour. Associated uncertainties have a negligible impact on the dose limits, once the other types of uncertainties are considered.

Uncertainty in the gamma field provides an upper limit because the extrapolation of intensity toward GZ along the west boundary of the display area may underestimate the close-in intensities. The extrapolation, based on intensity data from wind-transported fallout, does not account for the contribution to the gamma field near GZ from fallout associated with the nuclear cloud rise. That intensities

near 500 yards from GZ were likely higher than calculated in Section 4 is suggested by the isointensity contours of Reference 10, derived from the rad-safe surveys of Reference 8. It is possible that the 5 r/hr rad-safe limit was reached during the tour, either at 500 yards or slightly farther from GZ. The maximum dose is obtained from calculations with the limit at 500 yards. An increased exponential gradient between 2000 yards and 500 yards is consistent with the service observers having viewed the display at 1000 yards within their 2.5 r/hr rad-safe limit at about H+1½ hours (Reference 10). Corresponding adjustments to the exponential gradient on the eastern boundary of the display area are constrained by the observers' known walk-through of the displays there. The film badge dose resulting from these considerations is 1.1 rem in excess of that calculated in Section 4.

Variations in the route taken by the 2nd Battalion tend to reduce the time spent near the rad-safe limit. Apart from not advancing as far forward as radiologically permissible, the major likely variation is that, while returning to the trench area, the battalion crossed over to the west radial on the road at 2500 yards from GZ rather than skirted the high-intensity area cross-country. Once having left the east radial by a few hundred yards, the marines would have noted rapidly decreasing intensities. Very little dose would have been accrued thereafter. The reduction in calculated dose resulting from this scenario is 1.2 rem.

The range of total calculated film badge dose to the 2nd Battalion is  $3.0^{+1.1}_{-1.2}$  rem (0.1 rem less for Company E).

#### 5.1.3 Marine Air Group -16

Most of the dose to the helicopter crews was from the bus tour through the display area. Because they are calculated to have been near 5 r/hr while passing the innermost displays, the uncertainty in the gamma field results in a possible additional dose of less than 0.1 rem. For the field as calculated, the possibility exists that, when the buses reached the displays at 1000 yards from GZ, rad-safe personnel had not updated the limit line so as to permit further progress. In this case, the calculated dose is reduced by 0.2 rem. The timing of the bus tour is less certain than for those on foot. The available references provide no indication of when the buses were to return



to the trench area. A modification of the scenario described in Section 4 that has an impact on the dose is the addition of a two-minute stop at each display grouping for control personnel to summarize the damage to the displays. An additional dose of 0.3 rem results, significant relative to the calculated dose because of a large fractional increase in the time assumed for the tour. The total film badge dose to the helicopter crews is calculated as  $0.5^{+0.3}_{-0.2}$  rem.

The possible encounter of a helicopter with the nuclear cloud stem is also considered. Other Marine helicopter crews airborne at Badger and other shots reported accidentally encountering intensities of 50 r/hr on more than one occasion while probing near the stem (Reference 11). It is therefore conceivable that a MAG-16 helicopter also did so while evading the stem enroute to the trench area. An indication of the variation of intensity with distance from the stem is given by the data of ground personnel. The peak intensities of 1 r/hr at the command trench and 50 r/hr along the east radial, about 600 yards distant, provide an estimate of an exponential gradient likely applicable to a helicopter pass. For a helicopter approaching the stem radially at 70 knots, the total time from 1 r/hr to 50 r/hr and back would be about a half minute. The film badge dose resulting from that excursion in an exponential gamma field would be less than 0.1 rem. Even with ten extra seconds for a turnaround or for a tangential approach, the dose would be only 0.2 rem. Thus, the range of total film badge dose derived above is not materially affected by the inclusion of this uncertainty.

#### 5.1.4 Headquarters

The uncertainty analysis for Brigade Headquarters parallels that of the 2nd Battalion. Virtually the same reduction in calculated dose results from leaving the east radial at 2500 yards from GZ to cross to the west radial. As for the 2nd Battalion, the tight schedule of movements implies minimal uncertainty in dose resulting from uncertainty in timing. However, the uncertainty in the gamma field leads to less of a possible increase in dose. Because Headquarters preceded the 2nd Battalion through the display area, it was subject to higher intensities; a smaller variation in the gamma field would have resulted in reaching the rad-safe limit at the innermost displays. The associated increase in calculated dose is 0.8 rem. Thus, the total film badge for Brigade Headquarters is calculated as  $3.7^{+0.8}_{-1.2}$  rem.

## 5.2 TOTAL DOSE SUMMARY

The mean and range of total calculated film badge doses are summarized below for the major elements of the 2nd MCPAEB. It should be noted that the contribution from initial radiation was too small to be reflected in the totals to the number of significant digits presented.

Unit:	<u>1st Battalion, 8th Marines</u>	<u>2nd Battalion, 3rd Marines</u>	<u>2nd MCPAEB Headquarters</u>	<u>Marine Air Group -16 Helicopter Crews</u>
Total Film Badge Dose:	4.7 <sup>+2.1</sup> <sub>-2.3</sub> rem*	3.0 <sup>+1.1</sup> <sub>-1.2</sub> rem**	3.7 <sup>+0.8</sup> <sub>-1.2</sub> rem	0.5 <sup>+0.3</sup> <sub>-0.2</sub> rem

It is to be concluded from these ranges that most brigade personnel accrued in excess of 2 rem and that some personnel of the 1st Battalion may have exceeded the 6 rem maximum authorized dose for Desert Rock V personnel.

\*Right flank company only; less for other elements.

\*\*0.1 rem less for Company E.

## SECTION 6

### DOSIMETRY

Film badge dose records for participants in Shot Badger maneuvers are incomplete. Film badges were not issued to all troops as intended in the Operation Plan; after the previous Desert Rock V maneuver, it was decided to reduce the film processing workload by reducing the issue to one badge per platoon (Reference 3). However, Reference 5 states that two badges were issued per platoon. A film badge roster for the 2nd Battalion lists the 38 persons from all four companies to whom badges were issued. No comparable roster is available for the other brigade elements. Additional dosimetry from Marine Corps medical records lists doses for nineteen 1st Battalion and eight Brigade Headquarters individuals. It is not clear if the rehearsal dose was reflected in these film badge readings. As indicated earlier, badges for shot day were distributed the day before the shot. The residual radiation from the Shot Nancy display area was not large enough to significantly affect the film badge dose in either case.

Complementing the film badge data are pocket dosimeter data, especially as appear in Reference 5. Not only were pocket dosimeter readings the main radiation diagnostic reported by the brigade during maneuvers, but they were also the form in which the Marines reported aggregate dose totals (prior to film badge processing).

#### 6.1 1st BATTALION, 8th MARINES

Dose records for the 1st Battalion are limited to 19 individual medical records, including four to six from each of the four companies. The doses vary significantly within each company and from one company to the next. H&S Company troops received 1.0 to 3.29 rem, averaging 2.0 rem. The readings for Company B ranged from 1.59 to 3.5 rem, averaging 2.9 rem, while Company A recorded 3.41 to 6.2 rem, averaging 4.5 rem. The highest readings were Company C's 4.2 to 7.1 rem, averaging 5.4 rem. These dose ranges are qualitatively consistent with the radiation field and maneuver route if the 1st

Battalion was arranged as follows: Company A forward and on the left, Company B back and in the center, Company C forward and on the right, and H&S Company in the rear.

Dose reconstruction for the 1st Battalion right flank provides a shot-day estimate of 4.6 rem. The upper limit associated with this mean value, 6.7 rem, approaches the highest doses on the right flank. For comparison, pocket dosimeter readings for the battalion after the maneuver were reported to average 4.8 rem and to have a high value of 7.5 rem (Reference 5). From the available film badge readings, with each company weighted equally, the average dose to the battalion was 3.7 rem. It is not known whether the pocket dosimeter average was similarly obtained.

Both forms of dosimetry indicate that some personnel accrued doses in excess of the 6 rem exercise limit; calculations also indicate this possibility. The immediate cause of these overexposures is that the battalion commander was to react to actual dosimeter readings rather than to project dose totals with the aid of intensity meters. Because it took a finite time to withdraw from the contaminated area once the dose limit had been reached, some overexposure inevitably occurred. That dose levels reached the limit at all is largely because the 1st Battalion operated for an extended interval (0.4 hour) in intensities exceeding its 5 r/hr rad-safe limit. However, there is no indication in the operation orders that the troops even knew of an intensity limit; the maneuvers were to have been constrained by rad-safe limit lines posted (at 5 r/hr) by the 50th Chemical Platoon. Such posting was not possible for transient radiation from the passing cloud stem, during fallout deposition, and before rad-safe teams had surveyed the area. Unfortunately, there was no provision for the survey teams to otherwise indicate to the 1st Battalion the import of the radiological situation. Ultimately, the overexposures would have been prevented if an evacuation had been ordered upon realization that the stem might pass over some of the troops. However, there was likely an unwillingness on the part of the Desert Rock V Exercise Director to implement the evacuation plan, which would have aborted the entire exercise, when any affected units had an obvious route (west along the trenches) to evade the contamination, if necessary.

## 6.2 2nd BATTALION, 3rd MARINES

The 2nd Battalion film badge roster appears to be complete because the entries, in blocks by company, have consecutive badge numbers. Six to twelve badges were issued to each company, likely representing the issue of two-per-platoon (the companies, as constituted for the exercise, had different numbers of platoons). Average film badge doses for D, E, F, and H&S Companies were 3.8, 2.9, 3.1, and 3.3 rem, respectively (not included in these averages are film badge doses for four individuals who are discussed below). The similarity of these average doses reflects the degree to which the companies stayed together while touring the display area. Somewhat lower (pocket dosimeter) readings averaging 2.3 rem for the battalion were reported in Reference 5. No explanation is offered for the discrepancy with film badge readings.

The reconstructed (Section 4) 2nd Battalion shot-day dose of 2.9 rem (2.8 rem for E Company) matches dosimeter and film badge data about as well as possible. The range of uncertainty in the dose estimate ( $2.9 \begin{smallmatrix} +1.1 \\ -1.2 \end{smallmatrix}$  rem) reasonably accounts for the variations among reported doses.

An examination of individual film badge readings shows that four persons received doses of about 5.2 rem, at least 1 rem higher than other doses in the battalion. These four were from D, F, and H&S Companies. Among the more senior badged individuals, they were likely damage evaluators of the Marine equipment display. The damage evaluation team would have had to return to the area at a later time when all displays were radiologically accessible and thus would have accrued more dose.

Those few 2nd Battalion personnel with dose data in their medical records appear on the film badge roster; apparently only the personnel who wore the film badges ever had doses logged in their records. That the doses are in agreement give credence to dose data in medical records of other brigade personnel. Unfortunately, the yield from medical records is small.

### 6.3 MARINE AIR GROUP-16

No film badge data are available from medical records for this group; however, Reference 5 states that MAG-16 personnel received a total (shot-day) dose of about 1 rem. That this inexact value is greater than the calculated dose of  $0.4^{+0.3}_{-0.2}$  rem may reflect a longer than assumed stay time in the display area.

### 6.4 HEADQUARTERS

A final comparison can be made between dose records and the reconstructed doses for 2nd MCPAEB Headquarters. Of the eight film badge readings available from medical records, four are 3.42 rem, two are 3.8 rem, and two are 5.7 rem. The latter, including the dose for a chemical warfare & radiological defense officer, are likely for display evaluators, as discussed for the 2nd Battalion. The remainder are in excellent agreement with the calculated shot-day dose of 3.6 rem, but well in excess of the reported (Reference 5) pocket dosimeter dose of about 2 rem.

## SECTION 7 CONCLUSIONS

Elements of the 2nd Marine Corps Provisional Atomic Exercise Brigade, Exercise Desert Rock V, participated in Shot Badger while at the Nevada Proving Grounds during Operation Upshot-Knothole. Two battalions witnessed the shot from trenches 4000 yards (3660 meters) south-southwest of ground zero.

After the shot, the battalions initiated an attack on objectives 2000 yards from ground zero. The 1st Battalion, 8th Marine Regiment, did not achieve its objective because of radiation dose levels accrued enroute, and was barred from further action. The 2nd Battalion, 3rd Marine Regiment, reached its objective and then toured the equipment display area. One company of this battalion was airlifted to its objective by helicopters from Marine Air Group-16.

Initial radiation totaled less than 0.01 rem for the entrenched brigade at Shot Badger. Advance party personnel witnessed Shots Dixie and Ray but received no dose from either. The entire brigade rehearsed its exercise in the residual radiation field from Shot Nancy and accrued less than 0.1 rem.

Almost all of the radiation exposure of brigade personnel was due to residual radiation from Shot Badger. Typical doses for personnel in both battalions were 3 to 4 rem. The 1st Battalion had a greater range of doses, with film badge readings up to 7.1 rem, in excess of the prescribed dose limit for Exercise Desert Rock V of 6 rem. These doses resulted during their aborted maneuver in an area of high radiation levels. Doses to the 2nd Battalion were accrued almost entirely during the tour of the equipment display area.

The overexposures to some members of the 1st Battalion were fundamentally the result of plans not well geared toward the unexpected radiological situation and not providing for the proper dissemination of the pertinent radiological information. Radiologically experienced personnel would have been able to anticipate the adverse situation and make appropriate adjustments.

Film badge dosimetry and other records of activities for 2nd MCPAEB are sufficient to identify the personnel who had the greatest potential for exposure and to determine their specific activities. Dosimetry data correlate well with calculated dose, thus providing the necessary confidence in the calculated doses, and group activities, for those personnel with no dosimetry records.



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DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

System Planning & Analysis, Inc

ATTN: P. Lantz

Systems Resch & Applications Corp

ATTN: S. Greenstein

T. M. Dupuy Associates, Inc

ATTN: T. Dupuy

Tetra Tech, Inc

ATTN: F. Botwell

TRW Electronics & Defense Sector

ATTN: R. Ansbach

Vector Resch, Inc

ATTN: S. Bender



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